Radiation doses for sterilization of tephritid fruit flies

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In a database cataloguing radiation doses for arthropod sterilization and disinfection, out of 65 entries on Diptera species from 16 families and 22 genera, 21 species belong to the Tephritidae, confirming the importance of this group in pest management and international trade in agricultural commodities. Following Tephritidae are Culicidae (15 species), Glossinidae (6), Muscidae (6), Calliphoridae (5), Drosophilidae (1), Anthomyiidae (1), Oestridae (2), Agromyzidae (2), Chloropidae (1), Piophilidae (1), Cuterebridae (1), Psiliidae (1), Sarcophagidae (1), Sciaridae (1) and Tachinidae (1). The 21 species of Tephritidae belong to five genera, with Bactrocera having the largest number of species (9) being the subject of studies on sterility induction for pest control, followed by Anastrepha (6 species), Rhagoletis (3), Ceratitis (2) and Dacus (1). The mean dose to induce sterilization in Tephritidae is 65 Gy, which reflects an intermediate sensitivity to radiation compared to other Dipteran families. In general, the Tephritidae are a relatively homogeneous group. Less than 100 Gy is needed to achieve complete sterility in the five genera, and this confirms the recommendation of a generic dose in the range of 100–150 Gy to disinfest agricultural commodities for international trade.

INTRODUCTION

A database compiling data related to doses of ionizing radiation for arthropod sterilization and disinfection has been created. The objective of this database is to provide researchers, regulators and plant protection workers dealing with phytosanitary treatments, and sterile insect technique (SIT) programme operators, access to radiation doses and related references reported in the scattered literature. It assists in selecting optimum radiation doses that maximize the level of sterility required but also minimize damage to the quality of the sterile insect or the commodity.

The family Tephritidae is a large one; approximately 4000 species, arranged in 500 genera, are now known worldwide (White & Elson-Harris 1992). Fruit flies of the family Tephritidae are considered the most important quarantine insect pests in terms of international trade. The application of ionizing radiation to fruit flies has been reviewed by Hooper (1989) and Hallman (1999, 2000). The minimum absorbed dose required to provide control to the probit 9 level ranges from 50 to 250 Gy. However, for radiation quarantine treatments where fruit flies do not have to be killed immediately but only rendered sterile or incapable of completing development, a generic dose of 100 Gy has been reported to be effective (Hallman 2000).

The database called IDIDAS (International Data-base on Insect Disinfestation and Sterilization) includes data on major fruit fly species of economic importance. This review focuses mainly on analysing data pertaining to radiosterilization doses, and to show the general level of radiation sensitivity in fruit flies compared with other insect groups.

MATERIALS AND METHODS

Data compilation and analysis

A general procedure was adopted to select an optimum dose after extensive review of primary and secondary literature going back to the 1950s and 1960s. The primary sources included conventional entomological literature, and the secondary sources unpublished reports such as theses and proceedings. The International Nuclear Information System (INIS), hosted by the International Atomic Energy Agency (Vienna), and CABI Abstracts (1973–2002) bibliographic databases were also consulted.

The key parameters considered for the selection of the optimum radiation dosage were the mating performance, flight ability, longevity, fertility and fecundity levels of the fruit flies.

Unit of radiation

The outdated and discontinued units of radiation found in the literature, such as Roentgen equivalent physical (Rep), Roentgen (R or r) and Radiation absorbed dose (rad), were converted to Gray (Gy), the new unit of radiation in the International
Statistics
Wherever possible, results are expressed as the mean of the irradiation doses, and statistical analysis was done by Microsoft Excel data analysis tools called the Analysis ToolPak (Microsoft Excel® 2000).

RESULTS AND DISCUSSION
A search in the literature of the past 50 years, as reflected in the IDIDAS database, indicates that 234 species of arthropods, grouped in 159 genera, 73 families, 8 insect orders and 2 arachnid orders, have been the subject of irradiation studies for purposes of research or pest control programmes integrating SIT. Of these insect species, 30% belong to Diptera, 24.5% Lepidoptera, 23% Coleoptera, 13.6% Thysanoptera, 8.1% Acari, 7.2% Hemiptera, 3.1% Hymenoptera, 0.9% Dictyoptera and 0.45% Orthoptera. As the compilation of IDIDAS progresses with new research and additional information becoming available, the list of species on which radiation studies have been made will continue to expand.

Fruit flies have been the most investigated group of arthropods with regard to sterilization with ionizing radiation. Out of 65 dipteran species studied, belonging to 12 families and 21 genera that are currently in the database, 21 species are Tephritidae, confirming the importance of this group in pest management and international trade in agricultural commodities. The Tephritidae are followed by Culicidae (15), Glossinidae (6), Muscidae (6), Calliphoridae (5), Drosophilidae (1), Anthomyiidae (2), Oestrideridae (2), Agromyzidae (2), Chloropidae (1), Piophilidae (1) and Tachinidae (1) (Fig. 1).

The 21 species of Tephritidae studied are arranged in five genera – Anastrepha, Bactrocera, Ceratitis, Dacus and Rhagoletis – the most economically important fruit fly species. Within Tephritidae, Bactrocera has the largest number of species on which research on radiosterilization has been done (9), followed by Anastrepha (6), Rhagoletis (3), Ceratitis (2) and Dacus (1).

Tephritidae are intermediate in their sensitivity to radiation compared with other dipteran groups. The mean dose for sterilizing tephritid fruit flies is 65 Gy. Drosophilidae and Agromyzidae are the most resistant families, requiring 160 Gy to induce full sterility. Tachinidae are the most sensitive, requiring only 20 Gy to achieve full sterility (Fig. 2).

However, these mean dose values for each dipteran family should not be regarded as generic because in several cases only one species of the family has been investigated.

Tephritid fruit flies constitute a relatively homogeneous group. In general, less than 100 Gy is needed to achieve sterility in the five genera. Nevertheless, mean doses used for Ceratitis sterilization are twice as high as those reported for Dacus and Rhagoletis (Fig. 3). This difference may be related to species sensitivity, but largely also to the safety margins established by SIT programmes where the minimum doses applied to C. capitata vary among the programmes from 90 to 120 Gy (or even higher in some cases). This often-unwarranted increase in radiation dose clearly decreases male competitiveness, and thus the advantage expected from these small increases in sterility results mostly in reduced sterile male competitiveness. Hooper (1972) reported that males treated with 110 Gy performed poorly and their competitiveness was only 10 to 20% that of untreated males. Thus there is little advantage in exceeding a 90 Gy dose in this
species. In this case, by applying the lower dose and having more competitive males, fewer sterile flies would be needed in operational programmes to overflood the wild population effectively.

Most tephritid genera include species that are sterilized by doses ranging from 40 to 80 Gy (Fig. 4). Within the genera *Bactrocera* and *Anastrepha*, the sterilizing dose may differ by up to 50 Gy. Only in two cases, *B. philippinensis* and *C. capitata*, the dose reached 100 Gy. These high levels of radiation required confirm the validity of Hallman’s (2000) recommendation to use a generic dose of 100 to 150 Gy against immature stages of tephritid fruit flies in quarantine treatments for disinfestation of agricultural commodities.

According to collected data, *Dacus* required the lowest mean sterilizing dose, *Bactrocera* and *Ceratitis* the highest, but only a few representatives within each genus have been studied. Therefore, no statistical comparison among the mean doses of the five genera was possible, and no correlation between the dose and genus sensitivity was established. The correlation between radiosensitivity and phylogeny of insect orders or order groupings was previously found to be poor (Willard & Cherry 1975). Likewise, no correlation was reported between the dose level and certain insect biological parameters such as age, sex, diet, longevity,

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**Fig. 2.** Mean dose to induce 100% sterility in adult male dipteran families by irradiation in air. All treated as pupae except for Glossinidae spp. (as adults). Vertical lines represent the 95% confidence level of the mean (CL). Sources of irradiation are not comparable.

**Fig. 3.** Mean sterilizing doses of radiation for tephritid genera based on the number of radiosterilized species within each genus. In certain cases data for only a single species were found. Vertical lines represent the 95% confidence level of the mean (CL). Only doses of radiation of male pupae or adults irradiated in air were considered. Sources of irradiation are not comparable.
body size, and weight, in order to establish a radiosensitivity index (Menhinick & Crossley 1969; Willard 1970; Willard & Cherry 1975). This may be due, at least partially, to investigators reporting doses obtained under different biological and physical conditions. Investigating the radiosensitivity of 37 insect species belonging to eight orders and maintained in similar climatic conditions, Willard & Cherry (1975) found that the large and long-lived adults were more sensitive than the small and short-lived adults. Nonetheless, the radiosensitivity was evaluated mainly in terms of LD50 or LT50, and might be different when expressed in terms of sterility. If this correlation can be extrapolated to sterilization, there should be no difference in the radiosensitivities of fruit fly species since there are no major differences among species in body size or longevity. Although many of these tephritid species usually complete their life cycle in 3–5 weeks, some of the oligophagous or monophagous species tend to have longer-lived individuals.

No difference was found in radiation dose between tropical fruit fly species (Anastrepha, Ceratitis, Dacus and Bactrocera) and temperate species (Rhagoletis); the latter undergo a diapause and tend to have only one or two generations a year. Diapause is therefore not likely to be a major factor influencing fruit fly radiosensitivity.

There are other fruit fly species of economic importance for which sterilizing doses are not yet known. These include: B. carambolae, B. jarvisi, B. latifrons, B. occipitalis, B. papayae, B. passiflorae, C. cosyra, Myioparadalis pardalina, R. cingulata, R. completa, R. fausta and R. mendax.

Data collection and analysis showed several cases of inconsistency in the sterilizing dose even for the same species. This reveals the urgent need to harmonize the factors modifying radiation effects on arthropods, and to set standards for insect quality control and dosimetry. Such a harmonization process has been initiated by FAO/IAEA with the development of a standard dosimetry system for fruit fly irradiation, and the preparation of a standard operational procedure manual for quality control (FAO/IAEA/USDA 2003).

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